Phase II Project Summary

Firm: CFD Research Corporation (CFDRC)
Contract Number: NNX11CB99C
Project Title: Improved Design of Radiation Hardened, Wide-Temperature Analog and Mixed-Signal Electronics

Identification and Significance of Innovation: (Limit 200 words or 2,000 characters whichever is less)

Future NASA exploration of the Solar System including its planets, their moons, and lunar and Mars missions, require avionic systems capable of operating in extreme temperature and radiation environments. To design wide-temperature radiation-hardened electronics and predict their performance in space, advanced models and simulation tools are required at multiple levels. Contrary to digital circuits, single-event effects (SEE) in analog/mixed-signal circuits required for space missions had not been adequately addressed.

Project Innovations:

- Novel Radiation Hardened By Design (RHBD) solutions specific for analog/mixed-signal/radio-frequency (RF) integrated circuits (ICs) aimed for space applications.
- Advanced Mixed-Mode Simulations (3D physical models coupled with circuit/system-level simulations) of silicon-germanium (SiGe) heterojunction bipolar transistor (HBT) analog/RF circuits. Analysis is performed utilizing CFDRC developed NanoTCAD software package, which enables understanding of complex radiation-device-circuit interactions.
- New circuit design and layout methodologies/techniques for improved radiation hardness. They are based on the knowledge derived from 3D/Mixed-Mode simulations and experimental radiation/temperature data collected under the NASA Exploration Technology Development Program (ETDP), plus new measurements from this SBIR.
- Prototype chips that have been designed, fabricated, and tested for radiation performance. Samples have been delivered to NASA.
- In Phase-IIE, complementary first-principles modeling of displacement damage in compound semiconductor materials/devices such as SiGe HBTs and HgCdTe infrared photodetectors.

Technical Objectives and Work Plan: (Limit 200 words or 2,000 characters whichever is less)

The <u>overall technical objectives</u> of this effort are twofold:

→ Design, validate, and demonstrate innovative RHBD devices and analog/mixed-signal ICs in selected SiGe HBT technologies, and
→ Provide reliable mixed-mode CAD tools and physics-based models to enable design and verification of radiation-hardened custom mixed-signal and analog circuits for extreme environments of space.

<u>Work Plan</u> (tasks performed by CFDRC and Georgia Tech in consultation with NASA):

→ Improve SiGe BiCMOS TCAD models for extreme environment conditions (radiation + wide temperature) in the NanoTCAD software.
→ Use the MixCad software (CFDRC NanoTCAD simulator interfaced with Cadence Spectre circuit solver) to perform mixed-mode (TCAD + full external circuit) SEE simulations on selected circuits.
→ Implement selected RHBD concepts (e.g., inverse mode cascode SiGe HBT) in a TCAD model and analyze SEE performance of overall circuit under various operating conditions by mixed-mode simulations.
→ Experimental tasks: a) develop test boards for transient measurements; b) perform transient measurements using backside laser and focused ion microbeam; c) compare results with TCAD simulations; d) draw conclusions for model fidelity and define best-practices.

→ In Phase-IIE, develop physics models and first-principles approach to characterize extreme environment performance of compound semiconductor materials/devices including SiGe HBTs and HgCdTe photodetectors.

Technical Accomplishments: (Limit 200 words or 2,000 characters whichever is less)

Selected highlights of the technical results achieved in this project are presented below:

- → Advanced model for radiation-induced interface and bulk traps implemented in CFDRC's NanoTCAD software.
- → Single-event-transient simulations performed on high-speed (Gb/s) SiGe D-flip-flop (DFF) circuit based on: (i) decoupled current-injection and (ii) fully-coupled mixed-mode, to derive guidelines for required fidelity of modeling.
- → Small-signal analysis capability added to NanoTCAD simulator and validated against data for multiple test cases.
- → Molecular dynamics modeling approach developed to characterize displacement damage in Si and SiGe materials.
- → Wide-temperature and radiation response simulations performed on HgCdTe photodetectors.
- → SEE experiments:
  - o Broadbeam at LBNL Cyclotron
    - − TowerJazz, 0.18 μm cascode, X-Band low noise amplifier (LNA)
    - − CMOS bulk vs. SOI RF switches
    - − Verification of 1st generation SiGe GFC shift registers
  - o Two-photon-absorption laser at NRL
    - − IBM 8HP, 0.13 μm cascode, L-Band LNA
    - − IBM 9HP inverse-mode cascode test structures
- → <u>Gated-feedback cell (GFC)</u> architecture experimentally demonstrated for error mitigation of HBT digital latches and frequency dividers. <u>Inverse-mode operation</u> demonstrated for SEE hardening in 16-bit shift registers.
- → <u>Prototype chips</u> designed, fabricated, tested for radiation performance, and delivered to NASA.
- → <u>Publications</u>: 1 book chapter and >5 journal/conference papers on radiation-hardened, wide-temperature electronics.

NASA Application(s): (Limit 100 words or 1,000 characters whichever is less)

Prediction of electronic component performance in extreme environments (wide temperature range, radiation) is crucial for designing reliable electronics for all NASA missions, e.g., Europa Jupiter System Mission, Titan Saturn System Mission, sample return from Comet, Asteroids, and continued lunar and Mars exploration missions. Radiation-hardened and wide-temperature analog, mixed-signal, RF and digital circuits are essential for all the avionic systems used in NASA exploration projects. The optimized, wide-temperature RHBD designs from this SBIR will add to the pre-existing NASA "component library". The physics-based mixed-mode tools will help NASA to design rad-hard low-temperature electronics with better understanding and control of design margins.

Non-NASA Commercial Application(s): (Limit 200 words or 2,000 characters whichever is less)

Various critical analog, mixed-signal, RF and digital circuits are used in all space-based platforms, including DoD space systems (communication, surveillance, ballistic missiles, missile defense), and commercial satellites. Since modern electronics technologies and components are becoming increasingly sensitive to extreme environments, the mission lifetime and reliability are becoming increasingly difficult to assess, and a robust capability to predict their behavior increases confidence and reduces risk. The new RHBD designs and circuit/cell libraries, as well as the physics-based computer aided design (CAD) tools, can also be applied to cryogenic electronics for high-sensitivity, low-noise analog and mixed-signal applications, such as metrology, infrared (IR) imagers, sensors (radiation, optical, X-ray), radiometrology, precision instruments, radio and optical astronomy, infrared and photon detectors, and other high-end equipment. For all such devices and systems, predictive and accurate modeling and design tools reduce the required radiation/temperature testing, thus decreasing their cost and time to market or field application.

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